

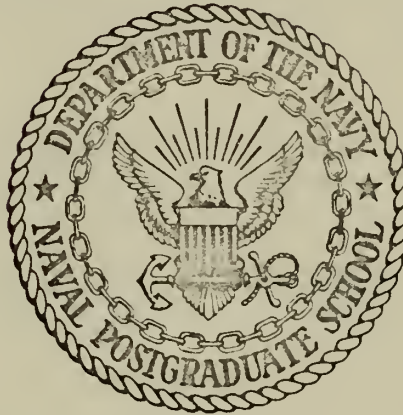
LABORATORY EXPERIMENTS ON WARM
FOG DISSIPATION

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THESIS

LABORATORY EXPERIMENTS
ON WARM FOG DISSIPATION

by

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September, 1972

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Laboratory Experiments on Warm Fog Dissipation

by

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ABSTRACT

Some of the more recent results of studies involving the use of hygroscopic materials and ionic surfactants as warm fog dispersants are covered in a brief survey of the literature. The fog chamber, equipment and experimental procedures used in this study are described in detail. Seeding agents utilized during these small-scale fog chamber experiments were limited to the use of hygroscopic materials, surfactants and ethyl alcohol. Results indicated that those hygroscopic agents tested, such as NaCl and glycerin, proved to be relatively effective warm fog dispersants compared to distilled water. The ionic and nonionic surfactants tested dissipated warm fog at approximately the same rate as distilled water and were considered ineffective. Ethyl alcohol appeared to initially increase the fog intensity, and thus, retard fog dissipation. Conductivity/Resistivity measurements and illustrations of the relative droplet sizes and shapes of the various agents used are also contained in this report. The effects on plants of four of the hygroscopic agents are also discussed and illustrated.

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Table of Symbols and Abbreviations

ac	alternating current
C	measured conductivity
cm	centimeter
CP	candle power
dc	direct current
gal	gallon
gm	gram
in	inch
k	conductivity cell constant
L	specific conductance
m	meter
M	molarity
mg	milligram
ml	milliliter
mm	millimeter
r	specific resistivity
R	measured resistivity
μ	micron

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The author wishes to take this opportunity to express his appreciation to his advisor, Professor C. L. Taylor, for his support, advice and guidance throughout this research.

My sincerest thanks to Mr. Stephen Rinard for his much appreciated advice and untiring assistance in carrying out the fog chamber experiments and other phases of this study.

Thanks are also due to Mr. Robert Smith, Research Administration Technician, who assisted in obtaining, calibrating and maintaining the electronic instrumentation, and Mr. Robert Schiele, Physical Science Technician, who made the spray nozzles, which were found to be most suitable for use in the fog chamber.

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I. INTRODUCTION

The study of fog is, indeed, one area in the field of meteorology which has had a great deal of vigorous research devoted to it in recent years. Fog is classified as either warm fog or supercooled fog, depending on whether its ambient temperature is above or below zero degrees Celsius. In actual practice, however, fogs having temperatures down to about -5°C may be treated using warm fog techniques since supercooled techniques are not practical until the temperature drops appreciably below 0°C . (Feit et al, 1970). In either case, fog consists of a visible aggregate of minute water droplets suspended in the atmosphere near the earth's surface, and which according to international definition, reduces visibility to less than one kilometer (0.62 miles) (Huschke, 1959). It is the latter stipulation, which distinguishes fog from mist, which may be considered as intermediate between fog and haze. Mist involves a lower relative humidity and does not restrict visibility to the same extent as fog.

The average individual has had numerous encounters with the inherent problems associated with fog. He has undoubtedly experienced the hazards of foggy highways and the delays in air travel. At the other end of the spectrum are those problems of the airline industry, the shipping industry and the armed forces, to whom fog is not just an inconvenience, but rather a contingency which is urgent and costly and interrupts both routine and special operations alike. With regard to the airlines, the twenty busiest airports in the United States are closed for a long-term average of 2700 hours each year at an annual cost of approximately seventy-five million dollars (Beckwith, 1968).

The armed forces are responsible for the protection of the people and the government of the country, without regard to meteorological phenomena. Consequently, the airline industry and the government have invested considerable sums of money in the search for efficient, inexpensive and ecologically safe fog dispersal systems primarily designed to meet aviation requirements.

It has been well documented that supercooled fogs have been cleared on an operational basis for a number of years, but there is currently no comparable system for dissipating warm fogs. A number of warm fog dispersal techniques are currently the subject of rigorous studies both under laboratory and field conditions. Some of the results have been quite encouraging with much attention being directed toward the use of hygroscopic materials as dissipating agents.

The author's efforts were focused on warm fog dispersion utilizing surfactants and several hygroscopic materials in numerous fog chamber experiments. The object of this paper is to report the results of these experiments with a brief preliminary discussion of several of the other current warm fog dispersal studies using surfactants and hygroscopic agents.

II. WARM FOG DISPERSAL

A. PRINCIPLES OF DISPERSAL

Efforts to disperse fog have intrigued cloud physicists and would-be weather modifiers for over three decades. Since the publication of Houghton and Radford's (1938) now classic work, most fog investigators have generally accepted their classifications of the two principles upon which all fog dispersal methods must be based. These are: (1) evaporation of the suspended water droplets and (2) physical removal of the droplets from the aggregate.

B. APPLICATION OF THE PRINCIPLES OF WARM FOG DISPERSAL

Silverman (1971) reported that warm fog dissipation research in the United States is focused upon the development of four main techniques, i.e., helicopter downwash mixing, the application of heat, hygroscopic particle seeding, and seeding with polyelectrolytes. Overall discussions of these techniques and reported results up through part of 1969 are covered quite thoroughly in the reports of Feit et al (1969) and Owens (1969).

This discussion will focus primarily on methods and results of the more current reported studies, which involve hygroscopic materials and surfactants.

1. Hygroscopic Seeding Agents

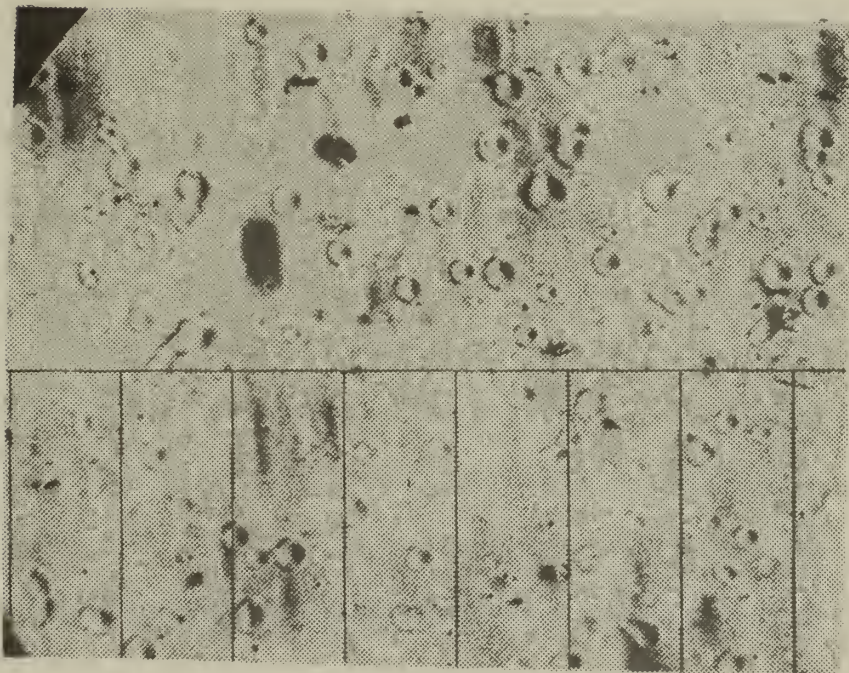
The use of hygroscopic agents is an application of the basic principle of evaporation of the suspended water droplets. When particles of salt (or other hygroscopic materials) are dispensed into an atmosphere containing fog droplets, the particles absorb water vapor from the air

in their immediate vicinity and condense the vapor into a liquid, thus, forming brine drops. This absorption reduces the vapor pressure in the immediate vicinity of the brine drops below saturation values, which in turn leads to the evaporation of nearby fog droplets. As the drops of brine grow larger and fall, they continue to absorb vapor from the air around them, leaving a "wake" of drier air along their path. The process goes on until the drops become so dilute that they are no longer effective in absorbing water vapor, or until they hit the ground. As the fog droplets evaporate, increased visibility with the gradual clearing of the air occurs. Figure 1 from Jiusto (1969) illustrates the growth of the saline drops at the expense of the natural fog droplets which primarily evaporate. It should be noted that the falling brine drops also "sweep out" some of the fog droplets as a result of coalescence.

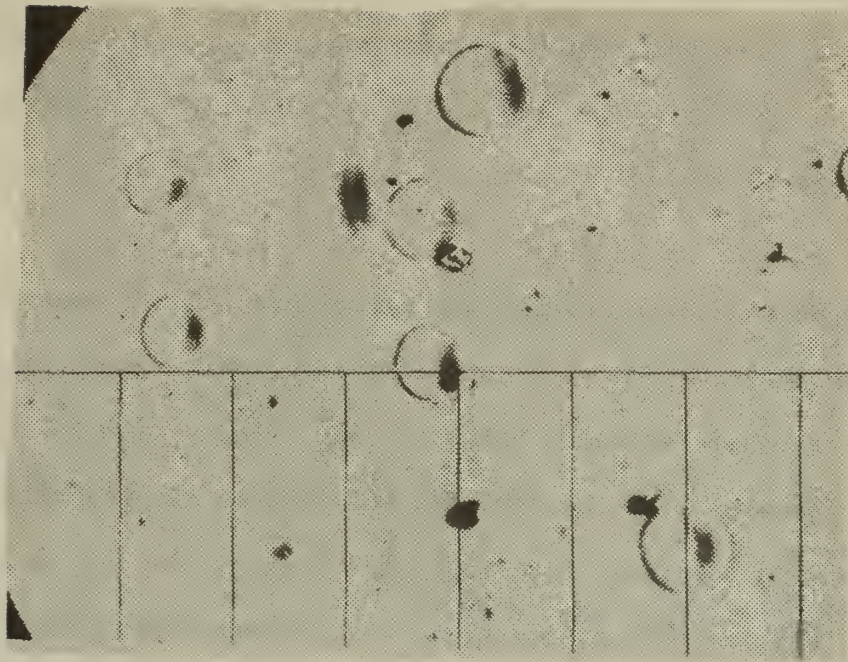
Over the years there has been periodic interest in the possibility of modifying fogs with hygroscopic materials. Houghton and Radford (1938) were the first to engineer an experiment, which produced repeatable visibility improvements in fog using a solution of calcium chloride as the hygroscopic agent.

It is now apparent from the literature that the major emphasis is currently on the use of hygroscopic agents in warm fog dispersal experiments. Although the ultimate solution to the warm fog problem appears to be far from attainment, hygroscopic materials have shown the greatest overall potential. Of course, many other techniques are also currently under investigation.

Jiusto (1969) suggested that the selection of hygroscopic



Control Fog



Seeded Fog

Figure 1 Droplet Replicas in Control Fog and Similar Fog
8 Minutes After Seeding with Giant Salt (NaCl) Nuclei.
(From Juisto, 1969)

materials for fog work is perhaps best dictated by: (1) capability of being readily milled to desired sizes, (2) handling ease or resistance to agglomeration, (3) cost, and (4) corrosive qualities. These four characteristics must certainly be expanded to include "ecologically safe".

Kocmond (1969) reported the results of airborne and ground-based seeding experiments, utilizing NaCl, at the Chemung County Airport near Elmira, New York. He concluded that the airborne seeding was more effective in causing fog dissipation, but, in most cases, the efficacy of both types of experiments was substantially reduced due to a considerable amount of clumping of seeding material. Thus, more effective methods for particle dissemination must be devised.

Juisto (1969) stated that the most critical parameter in developing an efficient fog-modification concept is the salt particle size. In order to avoid impractical salt mass requirements, particle size and concentration must be carefully prescribed. If submicron particles are used for seeding, the resultant saline drops will be too small to grow large enough to fall out, resulting in a decrease of visibility. On the other hand, if excessively large particles are used, they will fall from the fog before they have absorbed much moisture, and the larger salt mass required to produce and maintain a clearing will render the scheme economically impractical. Calculations indicate that for typical radiation fogs 5-to 10-micron radius salt nuclei in concentrations of a few mg m^{-3} of air are desired. Table I from the work of Feit et al (1969) summarizes the effect of particle size upon the time necessary to produce fog dissipation. The size of particles can change the effectiveness by several orders of magnitude.

Table I. The Effect of Hygroscopic Particle Size on a Treated Fog.
(From Feit et al, 1969)

Particle Diameter (Microns)	Effect
0.1	Treatment particles cannot grow large enough to fall out. Results in a net decrease in visibility.
1 - 2	Treatment grows into drops which stay suspended almost as long as the fog droplets.
2 - 5	Could be used to create a clearing if there is an hour or more available in which to accomplish it.
10 - 20	Can create clearings in 30 minutes or more.
30 - 60	Can create clearings in 10-20 minutes.
60 - 100	Extremely fast clearings are possible if sufficient material can be used.

Kocmond and Pilié' (1971) reported the results of additional warm fog seeding experiments, which were performed in Elmira, New York, to determine the potential of various sized and unsized hygroscopic chemicals. Urea, disodium phosphate and sodium chloride were tested and the sized materials were found to be more effective in causing fog dissipation, but considerable leeway in sizing was tolerable. No firm conclusions were drawn with regard to the relative efficiencies of the three chemicals tested, however, it was reported that the aerial seeding techniques were most effective during the latter stages of the life cycle of a fog. During these experiments, the gross effects on vegetation were noted as follows: sodium chloride was most damaging to vegetation growth, urea produced increased vegetation growth, but resulted in burning of leaf tips at the higher dosages, and disodium phosphate produced

slightly more lush vegetation.

The corrosive potential and detrimental effects on the ecology have certainly been recognized as major drawbacks in the use of NaCl for fog dispersal. For this reason, other materials, in addition to the two just mentioned, have been the subject of thorough investigations by various groups.

St.-Amand et al (1971) reported that during Project Foggy Cloud-1, 1968, a solution containing approximately equimolar ratios of ammonium nitrate, urea and water was developed at the Naval Weapons Center, China Lake, California. This solution has a density of 11.4 lb gal^{-1} (1.38 gm cm^{-3}) and is composed by weight of 5.14 parts ammonium nitrate, 3.86 parts urea and 1.00 part water. The vapor pressure, at standard temperature and pressure, is approximately 30 percent of that for water. Several successful field tests at Arcata, California, were conducted and these led to this solution becoming the agent of choice for subsequent experiments in 1969 and 1970 during which effects attributable to seeding were noted in 90 percent of the test cases. Clark et al (1971) reported that the above ammonium nitrate-urea-water solution provides a satisfactory balance of desirable fog dissipating properties, which include hygroscopicity, availability, cost, handling, ecological effects, chemical properties and drop growth. Hindman and Clark (1972), from recent work also done by the Naval Weapons Center, reported that glycerin was an effective hygroscopic agent but that the ammonium nitrate-urea-water droplets grew better than glycerin droplets in 100% and 95% relative humidity fogs.

Warm fog dispersal techniques using hygroscopic materials, among others, are the subject of studies throughout the world since the problem

is universal. In France, Paugam and Serpolay (1970) reported that non-corrosive sodium alginate powder appeared to give results comparable to those of corrosive NaCl powders, if the substance was used in amounts that were about six times larger than those used for NaCl.

It should also be noted that computer modeling has been used to establish specific relationships between the quantity and size of the seeding particle necessary to produce maximum visibility improvements (Tag et al, 1970). The treatments simulated included sized NaCl particles, sea water and the 9:1 solution of ammonium nitrate and urea to water developed at the Naval Weapons Center, China Lake, California. Such computer modeling is currently being done at the Environmental Prediction Research Facility, Monterey, California, the Air Force Cambridge Research Laboratory and by Rand Corporation.

2. Surfactant Seeding Agents

Surface active agents (surfactants) are an application of the principle of the physical removal of the droplets from the aggregate. It was originally believed that surfactants would reduce the surface tension of the water droplets and thus enhance the coalescence process, which would cause improved visibility as the larger droplets fall out.

Ionic surfactants have been the subject of a number of studies. Pilié (1969) reported that as a result of coalescence experiments conducted at the Cornell Aeronautical Laboratory (CAL); he and his associates concluded that ionic surfactants inhibit coalescence of drops with a plane water surface. They were also unable to detect any significant change in the coalescence behavior of treated and untreated drops

while attempting to observe the effects of surfactants on drop-with-drop coalescence. These observations and conclusions were contrary to the suggestions of such investigators as Elton (1953) and Benton et al (1958), who proposed that ionic surfactants could be used to promote coalescence.

Regardless of the exact process, ionic surfactants have produced droplet growth and shown signs of success in field experiments.

Ionic surfactants (polyelectrolytes), are compounds that separate into ionic components when dissolved in water. They purportedly cause the negative charges of droplets to be distributed on the surface and the positive charges on the interior. According to Coons (1972), a cloud of such charged droplets might serve to alter the "normal" atmosphere electric field and it is hypothesized that gross alterations in the electric field could be taken as qualitative indicators of the interaction of the polyelectrolytic agents with the fog droplets. Coons (1972) also reported that preliminary results, which were based on 30 hours of data, indicated that warm fog seeding experiments, using ionic surfactants, at the Seattle-Tacoma International Airport did show qualitative evidence of a favorable contribution to the movement of air traffic. The quantitative analysis associated with this investigation is now in progress.

It appears that surfactants are generally considered to be inferior warm fog dispersants, if they are effective at all, and consequently, relatively few studies seem to include the use of surfactants.

III. FOG DISPERSAL EXPERIMENTS

A number of potentially effective methods of warm fog dispersal have been tested in the last several years, and while some have been proven unfeasible for various reasons, others have shown promising results and are currently undergoing more thorough study, both in the laboratory and out in the field.

This study was limited to laboratory experiments primarily utilizing hygroscopic agents and surfactants, which are among those substances currently being investigated by others for use in warm fog dissipation. Considerably more effort has been directed toward the use of hygroscopic agents, which appear to be the more promising of the two. In addition, several experiments were conducted using ethyl alcohol.

A. SCOPE OF INVESTIGATION

Experiments were done on a small-scale basis utilizing the fog chamber and associated equipment described in detail later in this chapter. The purpose of these experiments was to obtain the necessary data to make relative comparisons of the effectiveness of the various agents used. The equipment utilized in this study precluded such details as the precise measurements of droplet sizes, however, the relative droplet sizes of the various agents used were recorded on gelatin slides and photographed for comparative purposes. Distilled water was used as the standard for comparing the relative effectiveness of the other seeding agents in dissipating warm fog throughout this study.

Initially, the impetus of this project was placed on the use of surfactants. There were two reasons for this approach: (1) it appeared

from the literature that there had been relatively little research done in this area, compared, for example, to the use of hygroscopic agents, and (2), it was intended as a more detailed follow-up on some results obtained and reported by Owens (1969). While these reported results on the effectiveness of the surfactants in dispersing fog were not positively conclusive, it was felt that they warranted further investigation. After numerous experiments using various surfactants at different strengths yielded convincingly negative results, subsequent experiments were conducted utilizing ethyl alcohol and several hygroscopic materials, such as sodium chloride and glycerin. A few common household detergents, which certainly contained wetting agents (surfactants), and various salts (hygroscopic agents), were tested. The results verified those reported in the previously mentioned thesis (Owens, 1969), however, the author felt that it was the salts and not the wetting agents that made these detergents effective dispersal agents. Conductivity/resistivity measurements were made on all agents used, in addition to obtaining traces and gelatin slides which demonstrated the relative effectiveness and the relative droplet sizes and shapes of the various agents."

B. METHOD OF APPROACH

The plan was to utilize the transmissometer concept to simultaneously monitor and record the relative intensity of the fog in two isolated fog chambers of equal volume. After a number of alterations and improvements were made to the initial chamber setup, it was felt that the subsequent fog dispersal experiments would yield reliable data for determining the relative effectiveness of the various experimental agents. The final fog chamber arrangement and experimental procedures are described in the next two sections of this chapter.

C. EQUIPMENT AND INSTRUMENTATION

1. Fog Chamber

A front view of the fog chamber is shown in Figure 2. The framework of the chamber was constructed of 1 in x 2 in and 2 in x 2 in common grade lumber. The outside dimensions of the chamber were 50 in x 49 in x 94 in. This basic chamber was then divided into two smaller chambers by installing two center walls of masonite board with a five in gap between these two interior walls. All surfaces of the two chambers were then covered with thin translucent plastic, which was stapled to the wood framework ensuring that both chambers were completely isolated from each other. The dimensions of the two smaller chambers were 50 in x 22 in x 94 in. Small openings were cut in one side of each chamber to accommodate the nozzles, which were located 82 in from the base and 11 in from each side of the chambers. Other openings 3 in x 3 in and 2.5 in x 2.5 in were cut out directly opposite from each other in both chambers for the photocells and lights respectively. These windows were covered with standard clear window glass, which was held in place with masking tape and all window centers were 22 in from the chamber base and 11 in from each side of the chambers. Several small clear plastic windows were installed to permit visual observations during experiments. A small flap was cut at the base of each chamber as an access for obtaining fog-droplet samples on gelatin slides. Larger flaps were cut near the base of each chamber for access and venting purposes.

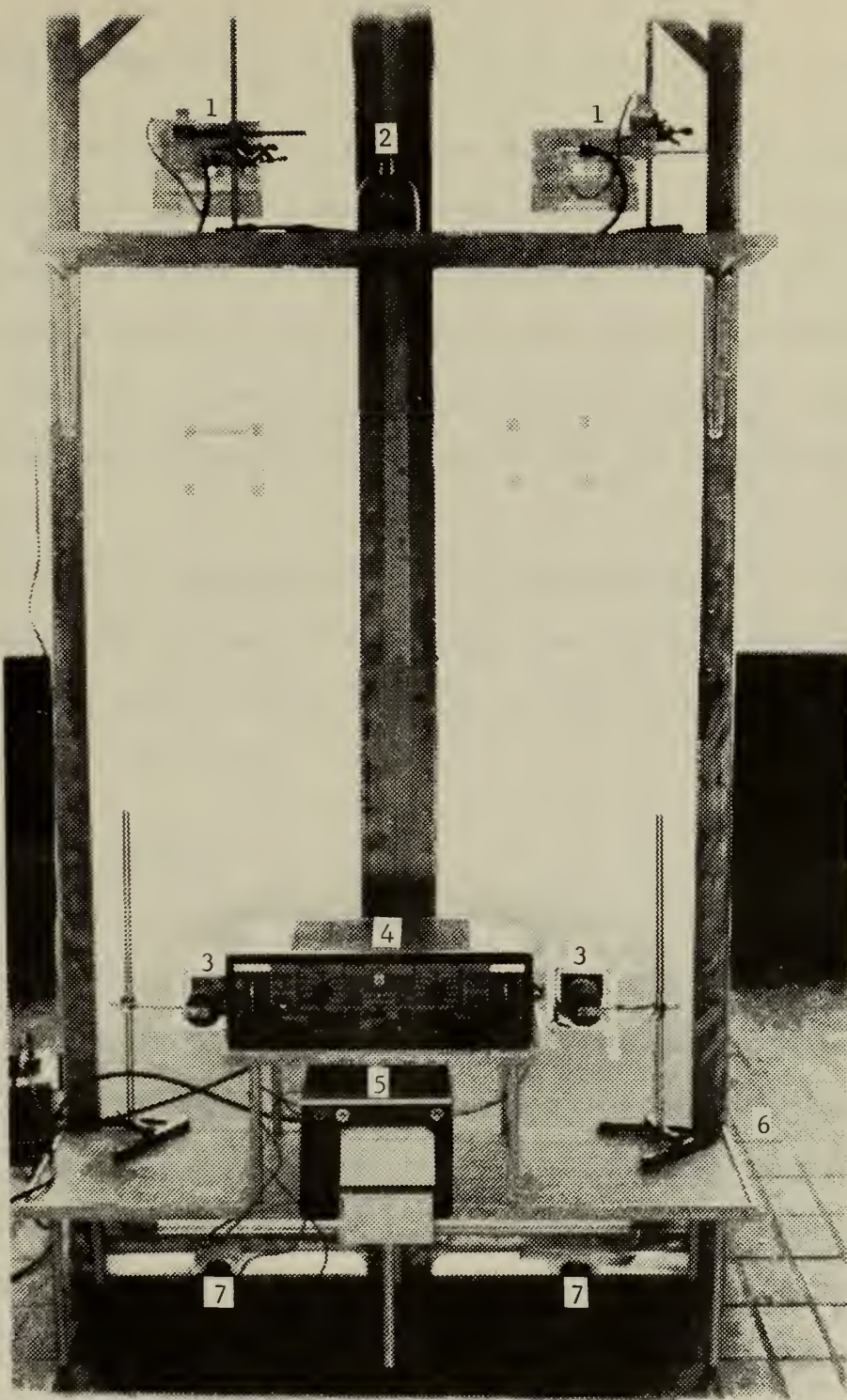


Figure 2 The Fog Chamber

- | | |
|----------------------|-----------------------|
| 1 Spray Apparatus | 5 Dual-Trace Recorder |
| 2 Air Compressor | 6 Thermometer |
| 3 Photoelectric Cell | 7 Slide Access |
| 4 Amplifier | |

2. Fog Generator

Fog was generated from distilled water utilizing two standard pressure cookers. A heavy rubber hose was secured to the steam outlet of each pressure cooker. A four-way connection, which was made of glass tubing, was used to vent these two hoses either into the atmosphere, or into the two chambers. Heavy clamps were used to control the flow of steam either into the atmosphere or into the two chambers, (see Figure 3).

This type of steam generator was considered superior because of its convenience and efficiency. It normally took about 15 minutes to initially generate steam and then only five to seven to fill the two chambers with a very dense fog.

3. Spray Generator

Two types of spray apparatus were used with varying degrees of success. Initially a Sprayon Products "Jet Pak" spray attachment, Figure 4, was rigged 12 in. from the top of each chamber. This rig consisted of a push-button and nozzle located above an aerosol can and a 100 ml. jar, which contained the solution to be sprayed into the chamber for the desired length of time. One person could simultaneously activate both nozzles into the chambers. This arrangement was intended to spray across the top of both chambers with a relatively even distribution of spray particles falling down through the fog. This method was deemed inadequate after several experiments when it was suspected and then visually verified that the pressure was excessive, such that a significant amount of the spray landed on the side of the chamber directly opposite the nozzle.

The same "Jet Pak" was then tried by spraying up from a position just above the light beam inside of each chamber. This required two persons and involved untaping a side flap, reaching inside the fog filled chambers with the "Jet-Paks", spraying up with the aerosol can and jar horizontal for the desired duration, withdrawing the Jet-Paks and taping the flaps shut again. It was anticipated that a more permanent remote controlled setup could be rigged, if the initial results showed some promise, however, this entire scheme was abandoned when freezing was regularly experienced at the nozzles causing sputtering and inconsistent spray action. This problem was caused by excessive seeding solution at the nozzle. With the jar in the horizontal position, the seeding solution free-flowed down the suction tube in the jar, accumulated at the nozzle and was frozen by the rapid expansion of the released gas from the aerosol can. This "icing" effect was not experienced in the original setup when the aerosol can and jar were vertically oriented.

The final spray apparatus consisted of handmade glass atomizer nozzles, Figure 5, which were constructed by the glassblower at the Naval Postgraduate School. Air was simultaneously supplied to both nozzles by a De Vil Bis air compressor, Type 501, resulting in each nozzle pulling a suction through a small rubber hose which was connected to a 100 ml. plastic bottle containing the seeding solution, Figure 6. Again, the nozzles were placed 12 in from the top of the chambers and sprayed across the top of the chambers through a small hole in the side of each chamber. The spray distribution across the top of each chamber appeared to be excellent with little, if any, spray reaching the side of the chambers directly opposite the nozzles. The pumps also provided a markedly more controlled and consistent spray, which was a major

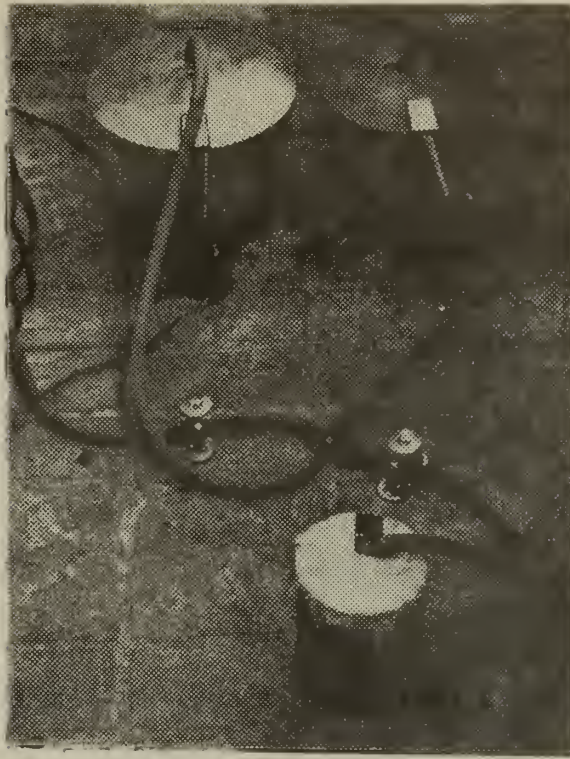


Figure 3 Fog Generator

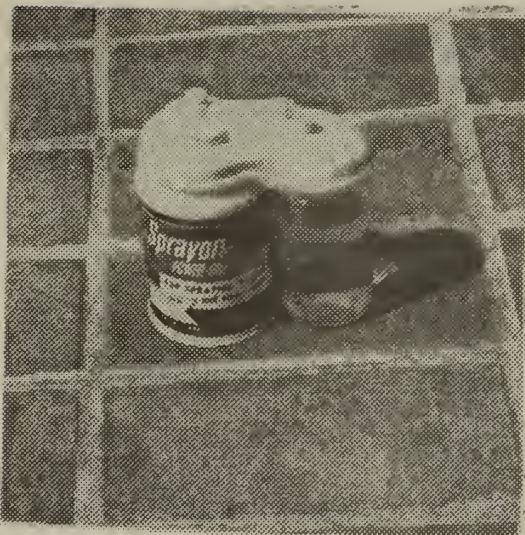


Figure 4 "Jet Pak" Spray Apparatus

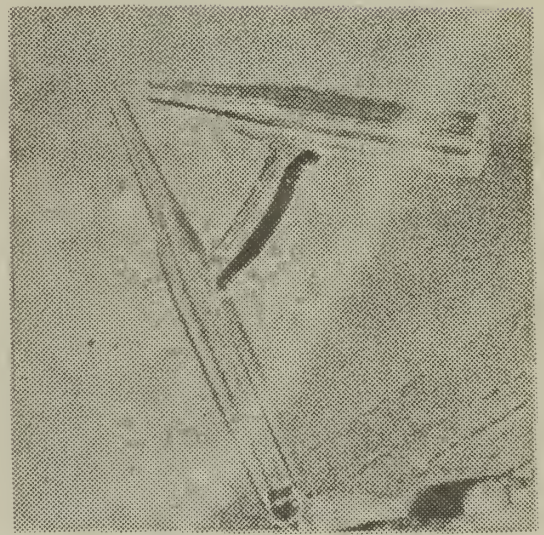


Figure 5 Handmade Glass Nozzle

improvement over the prior push-button aerosol can arrangements. In spite of the very slight variation in the volume output and droplet sizes of the two handmade nozzles, this improved spray apparatus was considered superior to the "Jet-Pak" spray attachment. The results of all experiments were verified using both nozzles and were always consistent.

4. Lights

A CENCO concentrated Filament Illuminator, which contained a 6-volt, 18-ampere microscopic illuminator bulb, was rigged for each chamber with the center of the telescoping lens system 22 in. from the base of the chambers, Figure 7. These lamps were powered by an auxiliary step-down transformer which operated on 115 volts, 50/60 cycles ac and they delivered a steady beam of high-intensity light to the photoelectric cells which were located directly across the chamber. VARIACS were used to set the lights at the desired intensity. A Weston Illumination Meter was used to determine the VARIAC settings which resulted in 25, 50, 75, 100, 150, and 200 candle power readings across a clear chamber.

5. Photoelectric Cells, Amplifier, Recorder

Two barrier-layer photoelectric cells were utilized to measure the light intensity, Figure 8. The beam of light generated an electromotive force resulting in an electric current, which could be measured with a galvanometer. The greater the intensity of light, the greater the current in the galvanometer. Initially, the galvanometer readings were recorded by hand at desired time intervals, which proved to be a cumbersome and inefficient means of gathering data. Several equipment

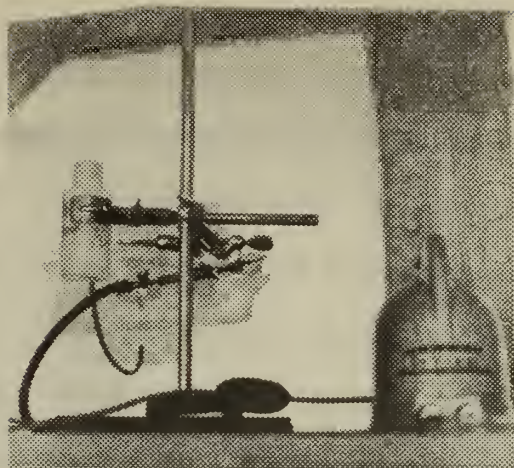


Figure 6 Spray Apparatus

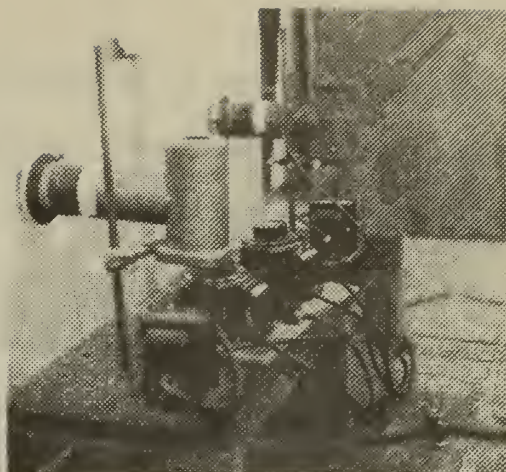


Figure 7 Lights and VARIACS

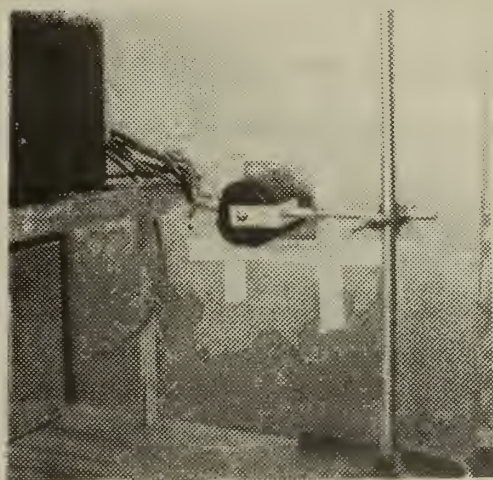


Figure 8 Photoelectric Cell

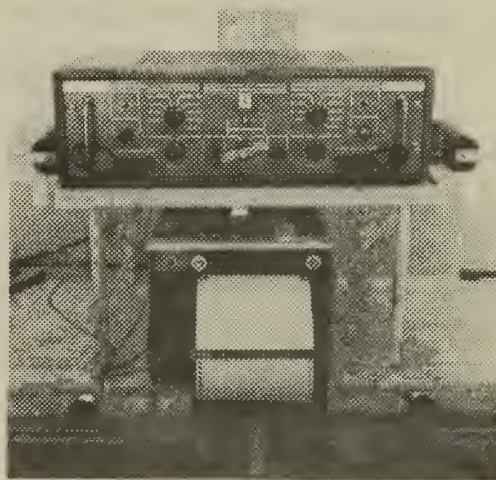


Figure 9 Amplifier and
Dual Trace Recorder



Figure 10 Conductivity Cell and Conductivity/Resistivity Meter

alterations and additions resulted in a drastically improved dual-trace permanent recording of experimental results. The low impedance output of the photoelectric cells was matched to a Brush Electronics Corporation amplifier by means of 263-ohm resistors in parallel across the output of the photoelectris cells in order to linearize the response to a wide range of light levels. Without these resistors, the linear response was limited to a narrow range of light levels. The Brush amplifier was a dual channel dc amplifier working into a dual channel galvanometer recorder, which was an Esterline-Angus Recti Graph, Figure 9. The maximum sensitivity of the amplifier was 50 millivolts, which was utilized at all times.

6. Resistivity/Conductivity Meter

A Barnstead Conductivity Bridge, model PM-70CB, and a mercury contact conductivity cell, Figure 10, were used to measure the conductivity and resistivity of all the experimental solutions. The cell constant (k) was calculated to be 0.205 cm^{-1} using the measured resistance (R) of a 0.02 M KCl solution, which had a known specific conductance (L) of $0.002768 \text{ ohm}^{-1} \text{ cm}^{-1}$. The measured resistance was 74 ohms. The cell constant, specific conductance and measured resistance of the conductivity cell are related by the equation, $k = LR$. Once k had been determined, the measured resistance (R) or the measured conductance (C) could be related to the specific resistance (r) by the equation, $r = Rk^{-1} = (kC)^{-1}$, noting $R = C^{-1}$.

7. Gelatin Slides and Preparation Procedure

Standard glass specimen slides for microscope use were coated

with a thin layer of gelatin by the author and were used to obtain relative droplet sizes during the fog chamber experiments. The gelatin mixture suggested by Juisto (1967) was used, i.e., one part (by weight) of commercial unsweetened gelatin powder to nine parts (by weight) of hot distilled water. After the gelatin was completely dissolved, blue food coloring was added to produce additional contrast for easier microscopic viewing of the droplet craters.

While the mixture was still hot, it was spread in a thin coat over standard pre-cleaned glass slides, which were placed on a flat surface to dry in an uninhabited room to minimize dust settling on the slides during the drying process. After the water was evaporated from the mixture, a very thin film of dry blue gelatin remained. The slides were then stored for later use.

D. EXPERIMENTAL PROCEDURES

All fog chamber experiments had to be conducted at night due to the location of the fog chamber in a room on the roof of a five story building. Large windows in the room precluded accurate light readings during daylight hours due to varying light conditions and reflections. Total darkening of the room was cost prohibitive.

All equipment was pre-checked and a trace, which indicated light intensities of 25, 50, 75, 100, 150, and 200 candle power, using the pre-determined VARIAC settings, was always made prior to the first experimental run of the night. All seeding agents, unless used in concentrated form, were diluted with distilled water to the desired strength.

1. The Basic Experiment

The actual procedure for conducting an experimental run was quite simple, although a second person was considered essential to carry out an efficient smooth-running experiment.

Initially, both lights were set at 200 candle power, which represented a clear chamber on the traces. Distilled water was used in the pressure cookers to safeguard, as much as possible, against tainting the experiments with an unknown factor. When steam was available from both pressure cookers, the two fog chambers were simultaneously filled with steam, at an equal rate through a system of hoses previously described in section C.2 of this chapter. The decreasing light intensity was monitored on the recorder until it ceased dropping in both chambers, at which time a very dense fog was present in the chambers and the steam was cut off. This normally took between five and seven minutes and resulted in recorded light intensities of less than 25 candle power and an increase of temperature within the chambers of six to ten degrees Fahrenheit. The temperature within the chambers at the time of seeding normally ranged from 77°F to 84°F.

As soon as possible after the steam had been cut off, an experimental seeding solution was sprayed for one minute into one chamber, while distilled water was simultaneously sprayed into the control chamber. A stopwatch was started at the moment the spraying commenced, $T + 0$, and the spraying ceased at $T + 1$. When droplet samples were desired, fifteen to thirty seconds after the spraying ceased, gelatin slides were exposed for one minute in the center of the base of the chambers through a tunnel arrangement with the slides attached to narrow wooden sticks.

After the spraying ceased at $T + 1$, the relative effectiveness of the seeding agent versus distilled water was monitored by simply observing the rate of increase of light intensity within each chamber as indicated on the dual trace recorder, Figure 11. Fog dissipation was allowed to continue for 15 minutes, $T + 15$, at which time the experimental run was terminated. Generally, ten to fifteen minutes more of natural dissipation and venting were allowed to elapse prior to the next run.

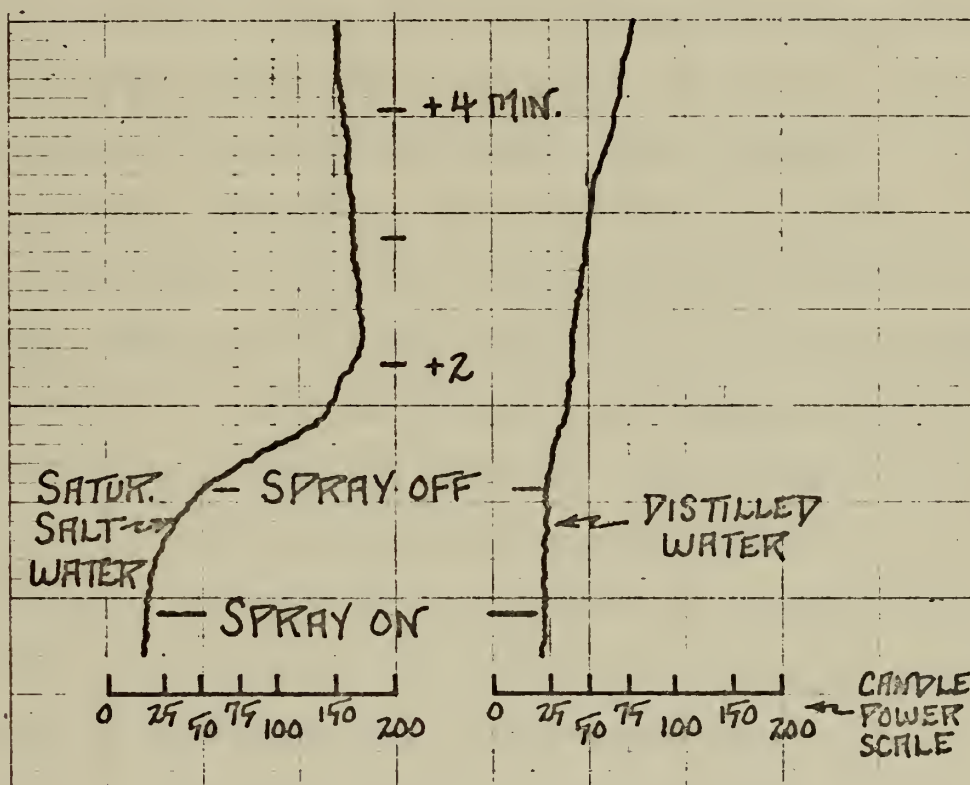


Figure 11 Sample of Dual Trace

Temperature was monitored by a standard meteorological mercury thermometer inserted through the side of the chamber near the base.

2. Additional Experiments

Normally three or four experimental runs were made per night over approximately a 2½-to 3-hour period. After the initial and all subsequent runs the same night, a very fine mist usually persisted in both chambers. These very small droplets were observed visually and their minor effect on visibility also showed up on the traces, which seldom returned to a completely clear 200 candle power reading. Much of this mist would disperse prior to the next run as a result of venting and natural dissipation, however, time considerations precluded waiting for a 100 per cent clear chamber prior to commencing the next run. The intensity and persistence of this fine mist appeared to vary slightly with different seeding solutions. Concentrated salt water seemed to result in the most intense residual mist. There was a slight accumulative effect over several runs, which simply caused the very dense fog to be a little more dense, when the steam was cut off, and slightly less clearing occurred at the end of the 15-minute dissipation period (T + 15). Although this minor variation in fog chamber conditions was observed, it was felt that the overall effect on the intent of the experiments was insignificant since the relative effectiveness of the seeding solution was still evident in all cases. The resulting traces, although seldom identical, were always consistent, eg., the glycerin solution (one part glycerin to one part water) was considerably more effective than distilled water regardless of the nozzle, chamber, or run number as illustrated in Figure 12.

3. Slide Observation and Photomicrography

A Bausch and Lomb Dynazoom laboratory research microscope with an integrated 35-mm camera system was used to examine and photograph the

droplet samples, which were obtained on gelatin slides during many of the chamber experiments. The microscope was equipped with 3.5X, 10X, and 43X objective lenses, 10X eyepiece lenses, and a zoom capability of up to 2X. Thick and thin blue filters were also used for better droplet contrast. The droplet craters were photographed on Kodak Tri-X Pan black and white film. Total magnification at the film plane was the product of the objective and zoom magnification multiplied by the 2.5 camera factor. All photographed samples, Figures 14a through 14p, were taken using the 10X objective lens and a 1X zoom magnification, which resulted in a total film magnification of 25X. During the picture development process, the magnification was increased to 50X. In general, the best photographic results were obtained using the thin blue filter, an exposure time of 1/8 second, and a microscope base illuminator setting of 16.5 volts.

4. Experimental Seeding Agents

Table II below is a list of all the seeding agents used during the project.

Table II.

Name Used	Trade Name	Manufacturer
Calgon	Calgon Water Conditioner	Calgon Corporation
Cascade	Cascade for Automatic Dishwashers	Procter and Gamble
Ethyl Alcohol	Ethyl Alcohol	Allied Chemical
FC-128 (Anionic)	FC-128	3M Company
FC-134 (Cationic)	FC-134	3M Company
FC-170 (Nonionic)	FC-170	3M Company
Glycerin	Glycerin Reagent ACS Code 1782	Allied Chemical
Ivory Soap (Bar)	Ivory Soap	Procter and Gamble
Joy	Joy	Procter and Gamble
Kwik Wet	Kwik Wet Nonionic Photo Wetting Agent	Edwal Scientific Products Corporation
Photo-Flo	Photo-Flo 200 Solution Temporary Packaging	Eastment Kodak Company
955	9-55 Fire Control Chemical	Gerald C. Bower, Inc.
Sat. Salt Water (Made using common table salt)		
Sea Water (Taken from Monterey, Bay, California)		

Some of these agents were used at various strengths as indicated in Table III.

Time (Min.)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Chamber #	Run #
Distilled Water	22	22	25	35	45	62	80	91	110	125	135	150	159	167	180	190	1	1
Distilled Water	22	22	28	40	53	71	83	90	103	120	133	148	158	170	182	190	2	1
Saturated Salt Water	18	54	165	170	164	158	154	154	154	157	159	162	167	172	173	175	1	3
Glycerin (1:1)	20	32	120	148	135	135	140	144	147	150	150	152	155	160	160	160	2	2
Glycerin (1:1)	12	23	33	89	115	130	140	145	150	153	160	168	180	182	185	200	1	1
Glycerin (10:1)	25	29	60	97	114	120	130	130	132	135	140	142	157	161	168	171	1	2
Glycerin (10:1)	20	25	60	80	91	97	108	115	125	134	138	141	150	155	160	164	2	1
Cascade	18	20	43	73	100	115	120	130	135	142	150	153	157	168	175	180	1	1
Cascade	17	25	70	90	100	112	118	122	130	132	138	144	150	155	155	155	2	2
Calgon	22	25	43	83	103	110	110	115	118	122	125	128	130	135	136	140	1	3
Calgon	17	23	50	85	90	93	104	115	120	129	135	145	150	155	160	167	2	1
Sea Water	30	33	70	91	95	108	114	120	128	130	135	140	142	149	157	160	2	3
Sea Water	10	15	25	70	90	108	109	110	115	119	120	135	138	140	147	150	1	1
Kwik Wet (Conc)	20	25	43	55	75	88	100	113	125	138	145	158	168	173	180	183	1	1
Kwik Wet (Conc)	25	28	33	45	50	60	75	78	90	98	110	113	120	130	135	142	2	1
Kwik Wet (10:1)	17	20	23	32	45	65	78	90	98	113	125	140	155	160	170	177	2	2
Kwik Wet (50:1)	22	23	35	42	61	82	95	112	123	135	145	155	170	190	195	200	2	1
Joy (10:1)	19	20	28	35	50	68	78	90	100	107	122	135	148	157	165	175	2	1
Joy (50:1)	25	29	40	53	72	80	92	108	120	130	142	155	160	170	182	190	2	2
Joy (50:1)	21	21	21	25	35	48	60	75	85	94	113	128	141	150	155	160	1	2
Cationic (FC-134)	17	20	31	35	55	70	80	92	100	112	128	139	144	148	160	163	2	3
Cationic (FC-134)	21	22	25	33	47	63	75	85	95	104	117	125	138	140	148	154	2	2
Conc. Ivory Soln	20	23	30	38	53	70	80	100	115	125	140	148	155	160	173	180	1	3
Conc. Ivory Soln	19	20	27	35	50	72	83	97	109	120	130	145	155	162	170	173	2	4
Photo Flo (Conc)	12	16	25	35	45	50	60	70	75	85	93	100	110	114	125	138	2	3
Photo Flo (Conc)	20	20	27	36	40	53	75	90	100	113	128	142	160	169	180	185	1	1
Anionic (FC-128)	12	13	20	25	37	49	70	84	90	108	120	134	140	148	158	165	1	3
Anionic (FC-128)	17	19	23	27	33	53	68	83	90	103	114	130	138	150	160	168	2	1
Non Tonic (FC-170)	12	15	20	24	38	50	63	76	87	95	108	117	130	139	142	150	2	3
955 (Conc)	8	15	19	20	25	40	57	70	80	85	104	117	125	132	145	150	1	1
955 (Conc)	19	21	25	28	38	46	50	59	70	76	88	95	100	115	120	122	2	2
955 (10:1)	17	17	20	25	35	48	58	70	77	85	90	106	115	128	140	150	2	3
Natural Dissipation	12	17	18	20	25	31	48	75	90	100	110	125	138	150	158	160	2	4
Ethyl Alcohol	85	57	58	70	75	83	100	110	120	129	138	150	152	154	162	170	1	3

Table III. Transmitted Light Intensity as a Function of Elapsed Time.
The numbers are the measure of the intensity of light in candle power transmitted through the fog chamber as a function of time.

E. DISCUSSION OF RESULTS

1. Fog Chamber Experiments

Figures 12 and 13 show four samples of actual dual traces made during the fog dissipation phase of the experiments. Figure 12 demonstrates the relative effectiveness of a hygroscopic agent (glycerin) while Figure 13 shows the relative ineffectiveness of three surfactants (KWIK WET, FC-128, FC-134, and FC-170). The data in Table III were taken from some of the many traces made during repeated experiments using both chambers. Two hundred candle power (CP) represented a clear chamber and the 8 to 25 CP at time zero ($T + 0$) was indicative of a very dense fog. While the candle power values in Table III are not necessarily exact due to minor reading errors while extrapolating the data from the traces, they are certainly considered adequate for determining the relative effectiveness of the various seeding agents. The effectiveness of the various seeding agents was determined based on a relative comparison with the fog dispersing capability of distilled water, which was only slightly better than natural dissipation. It should be noted that ethyl alcohol (listed at the bottom of Table III) actually caused an initial intensification of the fog. This trend was consistently observed and was probably due to the high volatility of ethyl alcohol. The evaporation of some of the alcohol, as it was being sprayed into the chamber, caused the ambient temperature of the fog to decrease, which resulted in a further condensation of water vapor within the chamber and thus, the initial fog intensification.

Table IV lists the seeding agents and the observed results relative to the effectiveness of distilled water. Agents which cleared fog

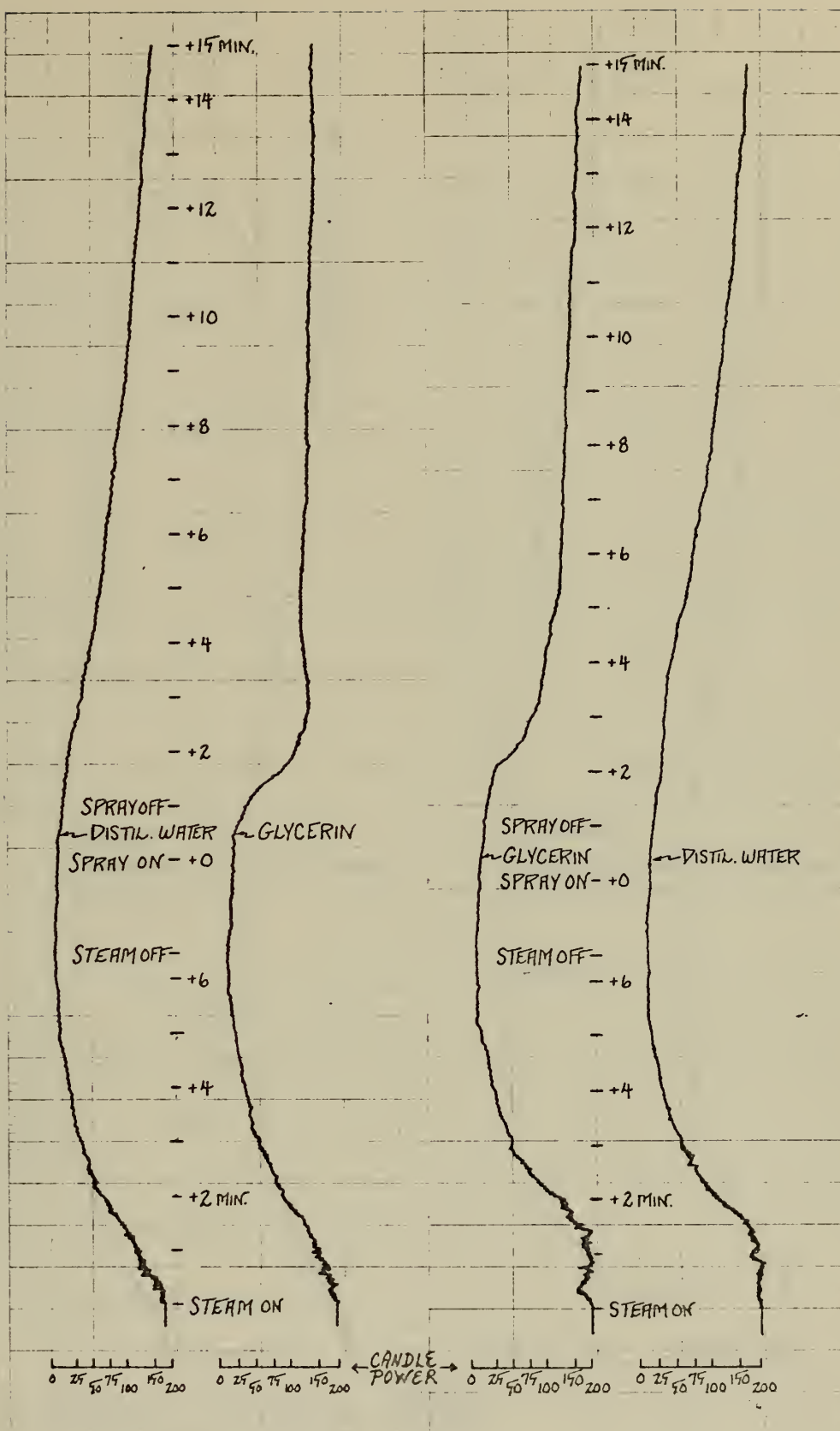


Figure 12 Sample Traces for a Hygroscopic Agent (relatively effective)

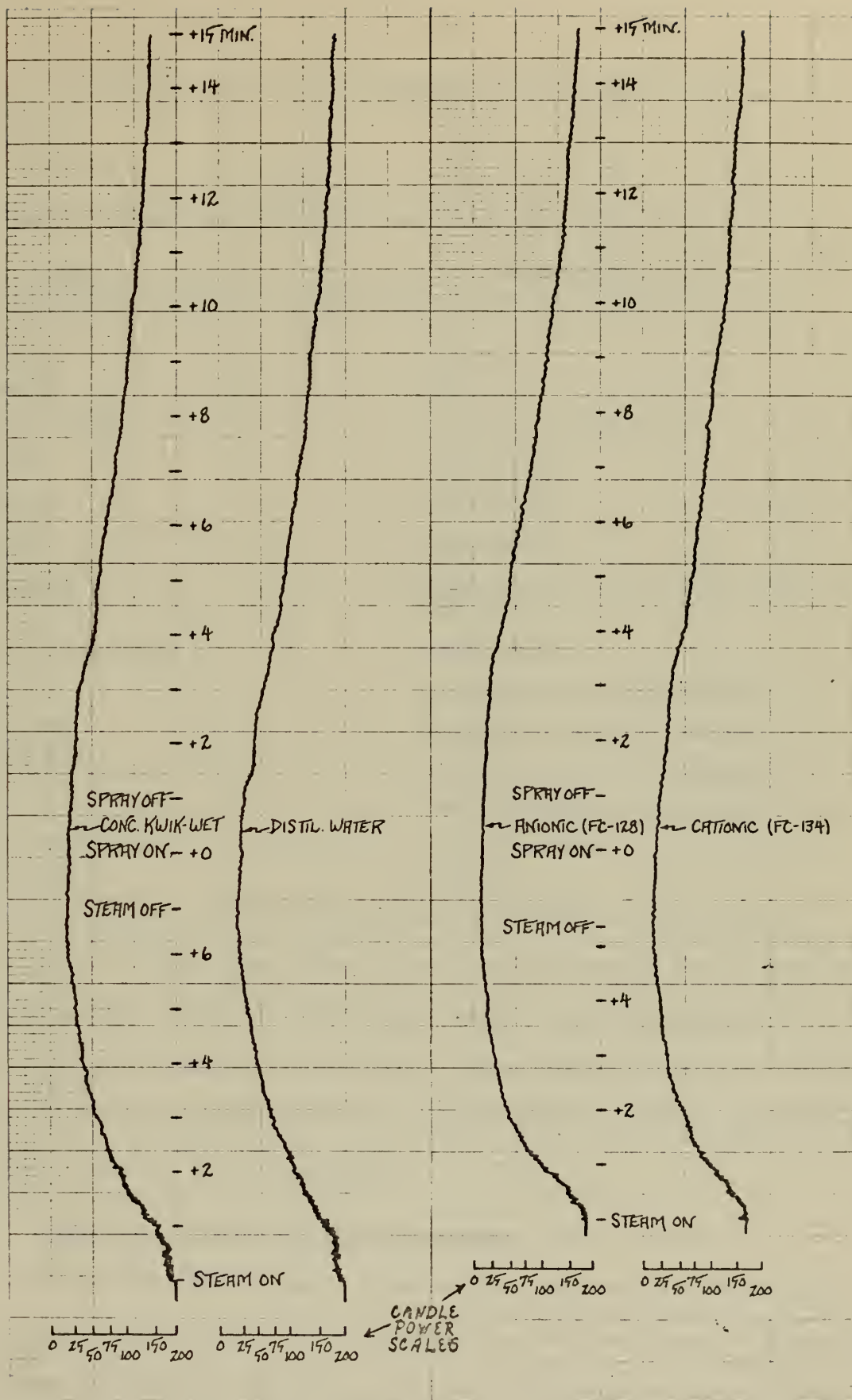


Figure 13 Sample Traces for Surfactants (relatively ineffective)

at approximately the same rate as distilled water were considered as ineffective.

Table IV. Relative Effectiveness of Various Seeding Agents

Agent	Observed Results
Calgon	Effective
Cascade	Effective
Ethyl Alcohol	Retarded fog dispersal
FC-128	Ineffective
FC-134	Ineffective
FC-170	Ineffective
Glycerin	Effective (1:1 more effective than 10:1)
Ivory Soap (Bar)	Ineffective
Joy	Ineffective (all strengths)
Kwik Wet	Ineffective (all strengths)
Photo-Flo	Ineffective (all strengths)
955	Ineffective (all strengths)
Sat. Salt Water	Very effective
Sea Water	Effective

It is evident from Table IV that the hygroscopic agents were relatively effective, while the surfactants were relatively ineffective. The author strongly feels that the relative effectiveness of Calgon and Cascade was due to the hygroscopic materials rather than the wetting agents (surfactants) contained in both products.

2. Resistivity/Conductivity Measurements

Table V lists the Measured Resistivity and Specific Resistivity of the experimental agents in increasing order and the Measured Conductivity decreasing from top to bottom. With the exception of glycerin, the most effective agents had the highest measured conductivity indicative

Table V. Resistivity/Conductivity Measurements

Seeding Agent	Measured Resistivity (R) (OHMS)	Measured Conductivity (C) (OHMS)	Specific Resistivity (r) (OHMS)
Saturated Sea Water	1.4	$> 11.99 \times 10^{-2}$	6.83
Cascade	4.7	$> 11.99 \times 10^{-2}$	22.93
Sea Water	5.0	$> 11.99 \times 10^{-2}$	24.39
Calgon	7.6	$> 11.99 \times 10^{-2}$	37.07
Joy (10:1)	27.5	36.40×10^{-3}	13.42×10^1
Joy (50:1)	91.3	10.95×10^{-3}	44.54×10^1
Sat. Ivory Soln.	16.60×10^1	60.20×10^{-4}	80.98×10^1
FC-134 (Cationic)	11.08×10^2	90.20×10^{-5}	54.05×10^2
"955" (10:1)	19.10×10^2	52.30×10^{-5}	93.17×10^2
Conc. Photo-Flo	24.30×10^2	41.20×10^{-5}	11.85×10^3
Conc. Kwik Wet	27.00×10^2	37.10×10^{-5}	13.17×10^3
Kwik Wet (10:1)	27.70×10^2	36.10×10^{-5}	13.51×10^3
FC-170 (Nonionic)	48.90×10^2	20.40×10^{-5}	23.85×10^3
FC-128 (Anionic)	49.30×10^2	20.30×10^{-5}	24.05×10^3
Conc. "955"	72.90×10^2	13.70×10^{-5}	35.56×10^3
Photo-Flo (10:1)	93.33×10^2	10.70×10^{-5}	45.53×10^3
Kwik Wet (50:1)	11.65×10^3	85.90×10^{-6}	56.83×10^3
Glycerin (1:1)	13.60×10^3	73.50×10^{-6}	66.34×10^3
Glycerin (10:1)	17.80×10^3	56.20×10^{-6}	86.83×10^3
Photo-Flo (50:1)	29.50×10^3	34.00×10^{-6}	14.39×10^4
Distilled Water	86.60×10^3	11.50×10^{-6}	42.24×10^4
Conc. Ethyl Alcohol	30.70×10^4	32.60×10^{-7}	14.98×10^5

of their being ionic as well as hygroscopic. Glycerin, on the other hand, is basically nonionic but very hygroscopic, which accounts for its effectiveness.

3. Relative Droplet Sizes and Shapes

Figures 14a through 14p illustrate various droplet samples obtained on gelatin slides. With the exception of Figure 14a, all illustrated slides were placed in the center of the base of the right chamber (see Figure 2) 15 to 30 seconds after spraying had ceased and were left exposed in the fog for one minute. Figure 14a shows a sample of the spray from the nozzle used in the right chamber when there was no fog in the chamber. The spray was turned on for several minutes and the slide was only exposed for 30 seconds after the spraying had ceased. All of these samples were taken in the right chamber using the same nozzle.

A detailed explanation of each slide sample would require information, such as density and viscosity of each seeding solution, the precise size of the droplets and the terminal velocities of the various droplets, which was beyond the scope and equipment capabilities of this study.

It appears that the hygroscopic effect of sea water, Figure 14c, and saturated salt water, Figure 14d, is quite clear when compared to distilled water, Figure 14b. It appears that some type of crystals remained in the droplets containing Calgon, Figure 14g. Also, the reduced surface tension of the droplets caused by surfactants is illustrated by concentrated Photo-Flo, Figure 14k, concentrated Kwik Wet, Figure 14l, and concentrated "955", Figure 14m.

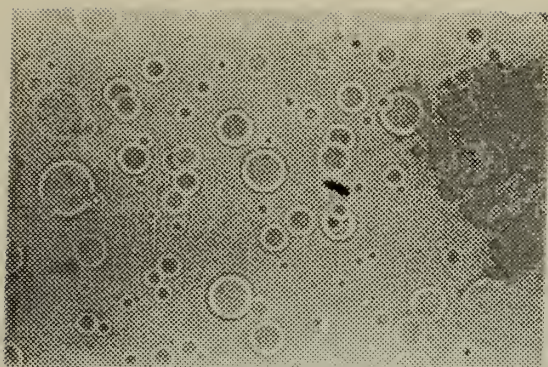


Figure 14a Spray (Distilled Water) Sample From Nozzle With No Fog in Chamber

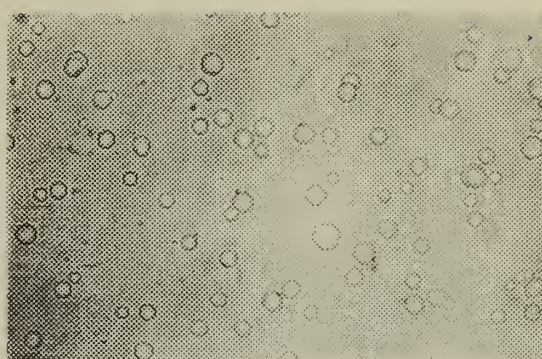


Figure 14b Distilled Water

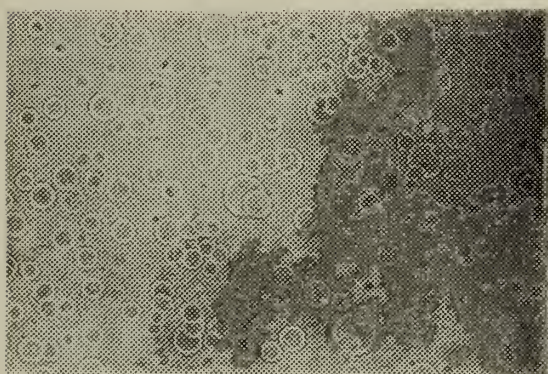


Figure 14c Sea Water



Figure 14d Saturated Salt Water



Figure 14e Glycerin (1:1)

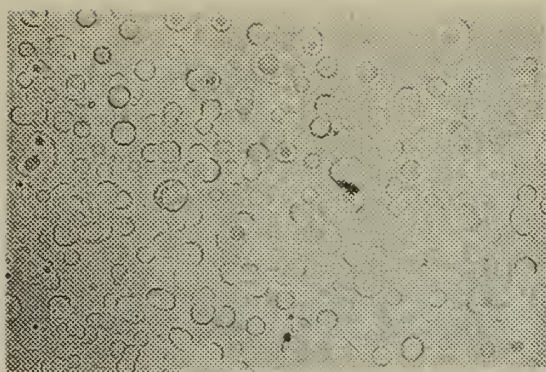


Figure 14f Cascade

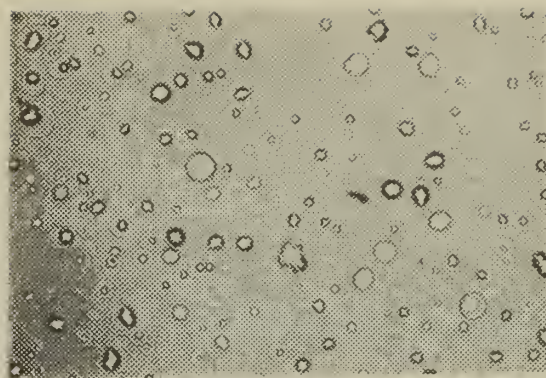


Figure 14g Calgon

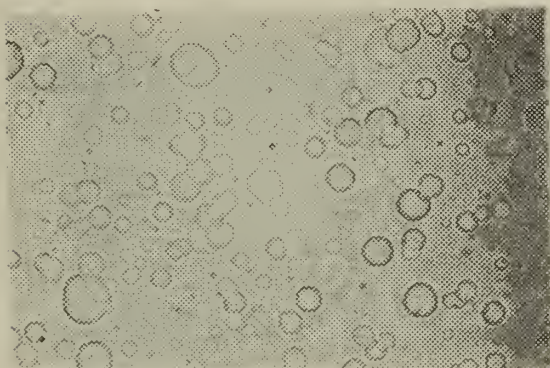


Figure 14h Joy (10:1)

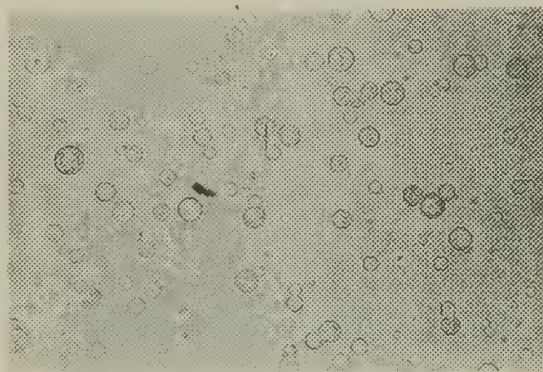


Figure 14i Saturated
Ivory Solution

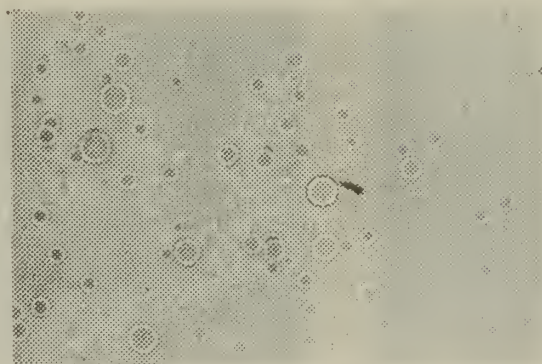


Figure 14j Ethyl Alcohol

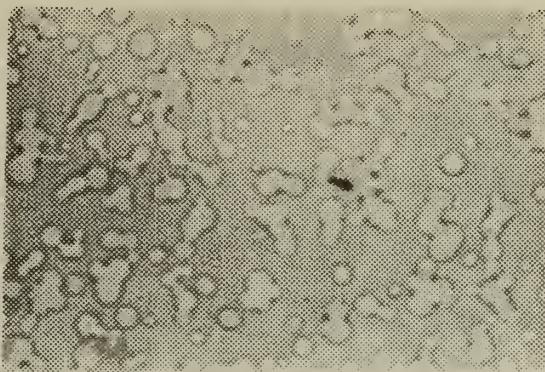


Figure 14k Conc. Photo-Flo

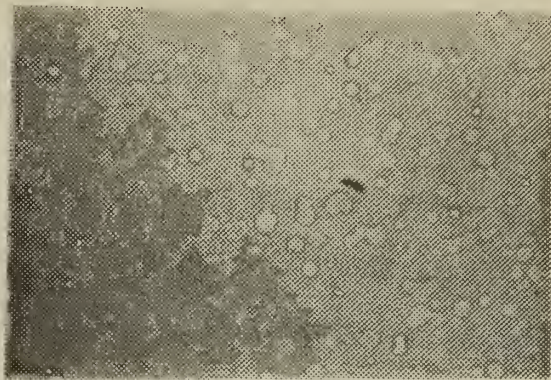


Figure 14l Conc. Kwik-Wet

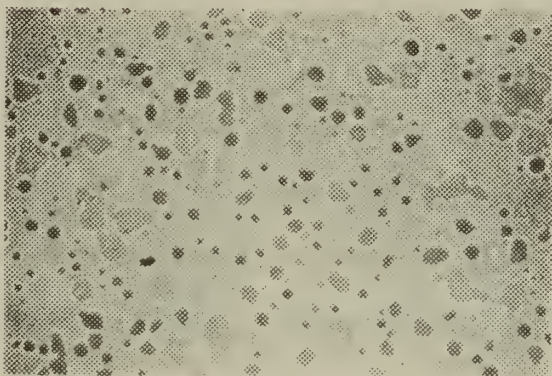


Figure 14m Conc. 955

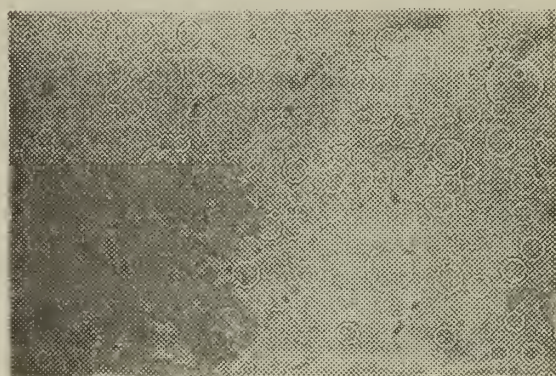


Figure 14n FC-128 (Anionic)

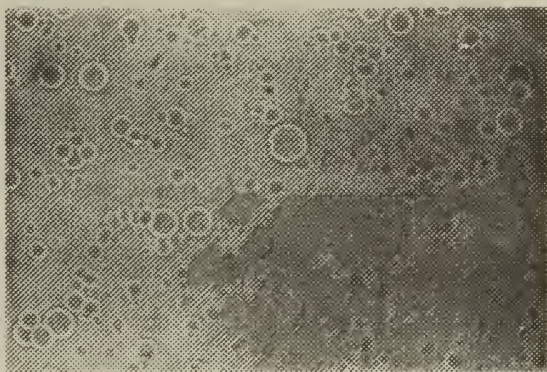


Figure 14o FC-134 (Cationic)

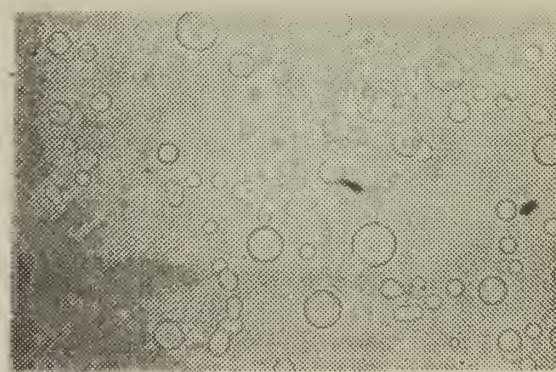


Figure 14p FC-170 (Nonionic)

4. Effects of Selected Seeding Agents on Plants

Six geranium plants were used during this phase of the study. Figures 15a through 15h are a chronological sequence of pictures showing the cumulative effects of repeated applications of four "effective" seeding agents. The Jet-Pak spray attachment was used to apply the seeding agents to the leaves of the plants. Plant #1 had nothing sprayed on the leaves and for some unknown reason, the base of the main stem withered between 20 July and 24 July. The plant eventually died with never any sign of new growth. Plant #2 was sprayed with distilled water. This plant was the smallest of the original six plants and, as to be expected, showed no ill-effects from the distilled water. Plant #3 was sprayed with Cascade. There was a white residue on all leaves and burning of the edges of some leaves, which eventually dried up, however, new growth continued to appear. Plant #4 was sprayed with saturated salt water and the ill-effects, which were anticipated, were rapid and clearly evident. That plant was dead after the second application and there was never a sign of new growth at the base of the main stem, in spite of regular watering with the rest of the plants. Plant #5 was sprayed with Calgon and initially showed very minor ill-effects in the form of brown discoloration in some of the leaves. Some of these leaves eventually dried up but new growth regularly appeared. Plant #6 was sprayed with glycerin (1:1), which was quite thick and sticky compared to the previous four sprays used. There was considerable browning of leaves, which eventually dried up, however, blooming did not appear to be hindered and new growth occurred regularly. It must be concluded that while Cascade, Calgon, and glycerin certainly did not enhance plant growth, they were not fatal to

the plants, in spite of the concentrated doses of spray, which would be highly unlikely in the field.

F. RECOMMENDATIONS

Recommendations for future studies of this type include:

1. Preparation of gelatin slides using 15% (by weight) gelatin to 85% (by weight) distilled water.
2. Initial test for general shape of droplets of the various seeding agents by placing sample droplet (eg. using eye-dropper) on a gelatin slide.
3. Effects of a wider variation of seeding times (one minute used throughout this study).
4. Several plants to be used for each agent being tested in order to ensure a more valid sample of the effects.

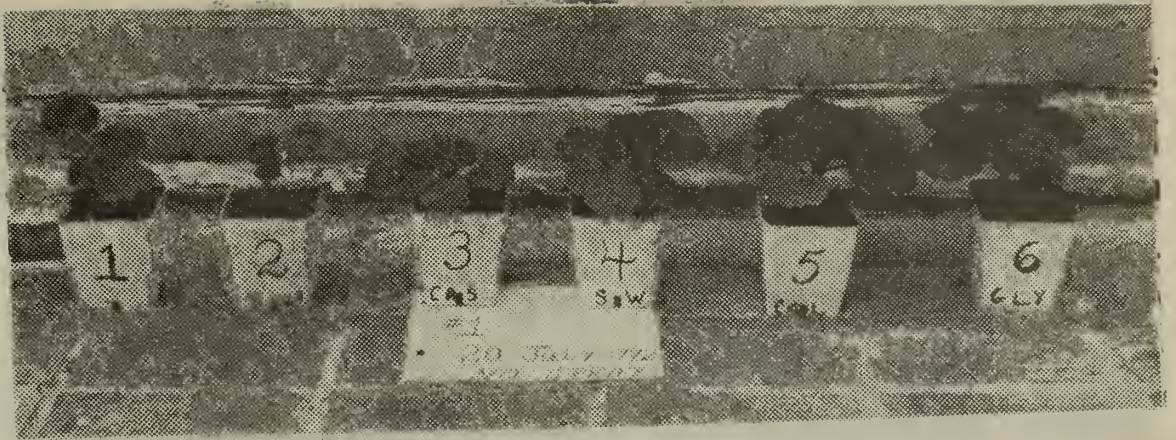


Figure 15a Original Plants

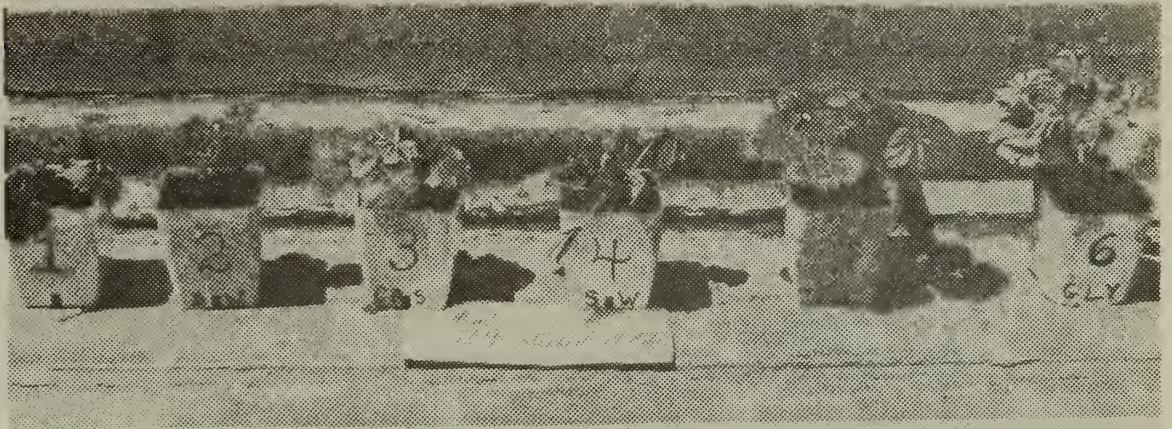


Figure 15b Effects of First Application (20 July 1972)

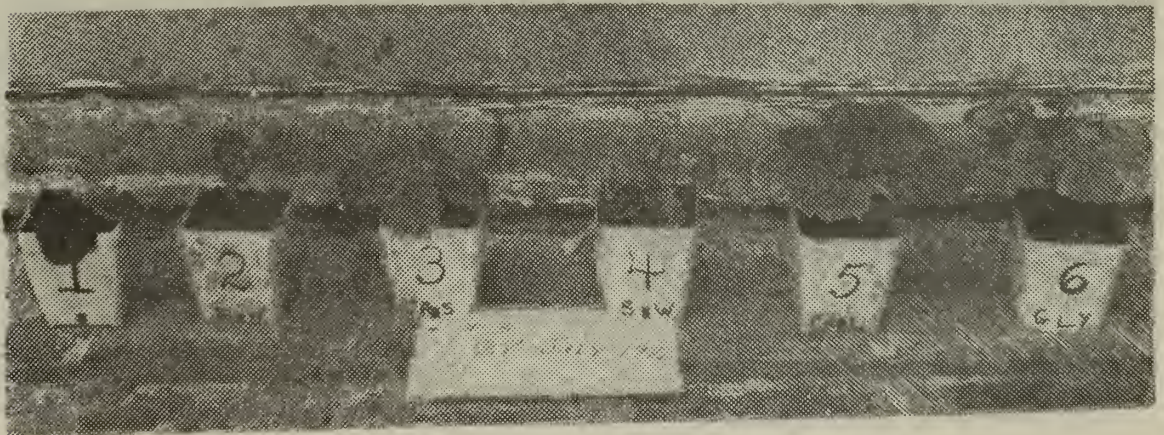


Figure 15c Effects of Second Application (24 July 1972)



Figure 15d Effects of Third Application (27 July 1972)



Figure 15e Effects of Fourth Application (31 July 1972)



Figure 15f Effects of Fifth Application (10 August 1972)



Figure 15g Effects of Sixth Application (17 Aug 1972)



Figure 15h Effects of Seventh (final) Application (24 Aug 1972)

IV. SUMMARY AND CONCLUSIONS

Small-scale laboratory experiments were conducted in a fog chamber to determine the relative effectiveness of various seeding agents as warm fog dispersants. These seeding agents were limited to hygroscopic materials, ionic and nonionic surfactants and ethyl alcohol. A light and photo-electric cell arrangement was utilized in two identical chambers to constantly monitor the fog intensity during the experiments and the results were simultaneously registered on a dual-trace recorder. Distilled water was always sprayed into one chamber as a control, however, it was considered ineffective as a warm fog dispersant throughout this study. The relative effectiveness of the various seeding agents was determined by comparing the fog dissipating capability of the seeding agents with that of distilled water. This comparison was made by examining the dual-trace recordings, which registered the transmitted light intensity in candle power within the two chambers as a function of elapsed time. From the numerous fog chamber experiments, it was apparent that the warm fog dispersal capability of ionic and nonionic surfactants was similar to that of distilled water and thus, considered ineffective. Ethyl alcohol appeared to retard fog dissipation. On the other hand, the hygroscopic materials, which included NaCl, glycerin, Cascade and Calgon, were relatively effective warm fog dispersants. It appears that the total dependence of surfactants on the coalescence process to remove fog droplets is far less efficient and effective than the evaporation process primarily utilized by hygroscopic materials.

Conductivity/resistivity measurements showed that all the hygroscopic agents, except for glycerin, had the highest conductivity which is indicative of a highly ionic structure.

Tests demonstrated that glycerin, Cascade and Calgon were considerably less damaging to vegetation than NaCl.

In conclusion, the author feels that glycerin should be the subject of a more thorough study as it is a relatively inexpensive, nontoxic and ecologically safe material.

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13. ABSTRACT Some of the more recent results of studies involving the use of hygroscopic materials and ionic surfactants as warm fog dispersants are covered in a brief survey of the literature. The fog chamber, equipment and experimental procedures used in this study are described in detail. Seeding agents utilized during these small-scale fog chamber experiments were limited to the use of hygroscopic materials, surfactants and ethyl alcohol. Results indicated that those hygroscopic agents tested, such as NaCl and glycerin, proved to be relatively effective warm fog dispersants compared to distilled water. The ionic and nonionic surfactants tested dissipated warm fog at approximately the same rate as distilled water and were considered ineffective. Ethyl alcohol appeared to initially increase the fog intensity, and thus, retard fog dissipation. Conductivity/Resistivity measurements and illustrations of the relative droplet sizes and shapes of the various agents used are also contained in this report. The effects on plants of four of the hygroscopic agents are also discussed and illustrated.			

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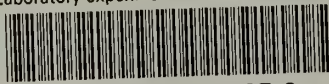
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